COMPACT COUNTERFLOW HEAT EXCHANGER

Background of the Invention

Field of the Invention:

(001) The present invention relates to heat exchangers, particularly, high-efficiency compact counter-flow heat exchangers.

Discussion of the Related Art:

(002) In the art of heat exchangers, it is generally acknowledged that fin effectiveness takes on values between zero and one, as constrained by conservation of energy principles. More specifically, the value of the fin effectiveness is always less than one for common engineering materials because of their finite thermal diffusivity.

(003) However, a premium is placed on system mass for aerospace design because of the energy expense of achieving and maintaining flight. Under ordinary conditions, each flight system performs a variety of functions to successfully complete its mission. A common function necessary to aerospace system operation is the power conversion function. To the extent that a given power conversion function can be accomplished more effectively by a given component of given mass, energy costs per unit payload can be decreased, or to the extent that a given power conversion function can be accomplished by a component of lesser mass, payload can be increased. Heat exchange is one such energy conversion function that finds common use in aerospace dynamic power systems.

Production of compact micro-channel heat exchangers 10 using micro-channel flow passages has yielded somewhat unreliable results because conventional fabrication methods cannot be controlled sufficiently well to yield consistent flow passage dimensions. Compact gas-gas heat exchangers are usually of the plate-fin type and are fabricated from thin sheets of material or plates to which are bonded, such as by furnace brazing, the fins. The fins are usually fabricated from strips of the same material used for the plates, forming a braze assembly. The fins and a sheet of braze foil are tack welded together prior to firing the assembly in a braze furnace. Alternatively, tack welding is used and welding of the many hundreds of fins is usually done by hand, which can be costly. Manifolds are usually welded to pre-inserted weld stubs which are included with the braze assembly.

(004) When the assembly of very small flow passage heat exchangers attempted however, distortion of the thin sheet-metal fins, weld splatter, arid braze drop-through often form significant and uncontrollable flow path obstructions. The present invention avoids the problems associated with conventional plate-fin construction by providing a pre-machined microchannel counterflow path in the form of a square tube having a particularly advantageous geometry. Opportunities for weld-splatter, braze drop-through and part distortion are restricted to the latter stages of the total assembly process which are finished by a reliable final machining operation, such as laser machining, water jet machining, electrical discharge machining, or conventional machining, resulting in consistent and controllable flow passage dimensions. Hence, a compact microchannel

heat exchanger is produced having a plurality of parallel tubes for carrying a working fluid a header and a tank assembly at each end of the tubes for directing working fluid through the tubes in a desired flow path. The compact counter-flow heat exchanger according to the present invention allows for an increase in heat exchange efficiency and effectiveness at a set mass, a reduction of heat exchanger mass at a set effectiveness, or a combination of the two. Such compact counter-flow heat exchanger offers a power designer system conversion more freedom for innovation on any given heat exchanger system.

Summary of the Invention

(005) A novel aspect of the present invention is a heat exchange system comprising a plurality of longitudinally extending and parallel fluid carrying tubes arranged in thermal contact with one another, each tube having at least one bend congruent to a bend in an immediately adjacent tube; and a first heat exchange fluid flowing through any one tube in a direction opposite to a direction of a second heat exchange fluid flowing through an immediately adjacent tube, thereby establishing a counter-flow heat exchange relation between the first and second heat exchange fluids.

(006) Another novel aspect of the present invention is a micro-channel recuperator including a core mass comprising multiple layers in a vertical plane of multiple fluid carrying tubes arranged adjacent to each together and a substrate layer disposed in a horizontal plane, alternating tubes having a longitudinal offset bend equal to at least the width of a tube, and fluid carrying counter-flow channels comprising alternate tube layers

communicating across the entire horizontal plane thereof, whereby the fluid carrying tubes of the core mass are directly adjacent to the fluid carrying counter-flow channels.

(007) Another novel aspect of the present invention is a method of making a heat exchanger comprising the steps of preparing a substrate layer of multiple square metal tubes arranged adjacent and physically attached to each other in a horizontal plane, each tube having a longitudinally extending offset bend; configuring multiple layers in a vertical plane of multiple square metal tubes arranged adjacent to each other and the substrate layer in a horizontal plane and having interposed between each layer of multiple metal tubes physically and communicating therewith a braze alloy thus forming a heat exchange core; causing the braze alloy within the core to bond the multiple layers of multiple square metal tubes forming a core mass comprising in a vertical plane, multiple layers of multiple square metal tubes arranged adjacent and physically attached to each other and the substrate layer; forming in alternate tube layers counter-flow fluid channels communicating across the entire horizontal plane thereof; providing the core mass with side containment shells and manifolds in communication with the multiple square metal tube core mass and the counter-flow channels; and brazing the heat exchanger to bond parts thereof together

(008) Another novel aspect of the present invention is method of thermal transfer comprising the steps of providing adjacent first and second fluid carrying tubes in heat exchange contact one with another; forming an offset bend in each tube; and flowing a first thermal transfer fluid through the first fluid carrying tubes, and flowing a second thermal transfer fluid through the second fluid carrying tubes, respectively.

Brief Description of the Drawings

Fig. 1 shows a typical baseline heat transfer arrangement;

Fig. 2 shows a heat transfer arrangement for a set or fluid channels according to the present invention; and

Fig. 3 shows the counterflow fluid flow streams according a typical baseline transfer arrangement.

Detailed Description of the Presently Preferred Embodiments

(009) Fig. 1 shows a typical baseline heat transfer arrangement comprising a heat exchange core assembly 10 of square-formed seamless channels 16, and an identical square formed seamless counterflow channel 18. The channels 16, 18 each have multiple square tubes 12 of equal dimensions, 10 and arranged in parallel configuration.

(010) Onto the substrate layer 22 are added seriatim multiple layers of the tubes 12, each provided with a particular geometric feature. The tubes 12 are stacked in a vertical plane and arranged adjacent to each other and the substrate layer 22. In other words, tube 12 comprising the channel 16, 18 or the assembly 10 are arranged, or "stacked", in ascending and descending column-like channels, both above and below one another, in an alternating checkerboard pattern, as shown in section A-A.

(011) In preparing the core assembly 10, each one of the tubes 12 forming channels 16, 18 is made of a suitable material having desired heat transfer characteristics, such as type 304 stainless steel. The tubes 12 are assembled by brazing, using for example, a high temperature braze alloy (90/10 Ag/Pb), as discussed below.

(012) Manufacture of the core assembly 10 comprises preparing a substrate layer 22 of multiple tubes 12 arranged adjacent and physically attached to one another in a horizontal plane. Although tubes 12 are shown in Fig. 1 and discussed herein as having a square internal cross-section, any suitable internal cross-sectional shape having desirable heat transfer characteristics would be useful in the present invention.

(013) Interposed between each layer of tubes 12 is a layer of brazing material or alloy

24 such as 90/10 Ag/Pb alloy activated to effect bonding of the individual tubes 12, such as by furnace brazing or any other well-known brazing technique. Upon completion of formation of the core assembly 10, headers and manifolds 20 are attached, also such as by brazing, to the core assembly 10.

(014) Fig. 2 shows that alternating ascending columns of tubes 13 of the present invention and are provided with a longitudinal offset bend that "jogs", or slightly deflected in the vertical plane. Each of the respective tubes 13 are offset, or jogged, in parallel and congruent fashion, upwards through a distance equal to the width of a tube 13.

(015) The longitudinal offset bend, or jog, in each tube 13 improves heat transfer between any two sets of tubes 13, so that a maximum surface area each tube 13 is in contact with material of type 304 stainless steel with which a silver base alloy is used for brazing. Moreover, with proper tooling table design, the heat exchange core assembly 11 can be formed with elastic tube deformation brazed in place. Any material other than stainless steel having desirable heat transfer structural and convection characteristics would be equally as useful in the present invention.

(016) Fig. 3 shows that the heat exchanger core assembly 11 is provided with a pair of headers or side containment shells 14. Each header or shell 14, which are positioned at opposing ends of the assembly 11 is configured to function not only with the tubes 13, but cooperatively also with the alternating counter-flow channels 16, 18, which are cut parallel to the horizontal plane of the core assembly11. Engaging the headers or side containment shells 14 are manifolds 20 which communicate with a cooling fluid source. The cooling fluid source supplies circulating cooling fluid to the heat exchanger in flow directions depicted by the arrows.

(017) The heat exchanger of the present invention functions in the following manner. Fluid streams "A", and "B" of different temperatures are introduced to the heat exchanger in the directions shown by the arrows in Fig. 4. The inlet for stream "A" directs fluid flow into tube 13, via respective manifolds 20. The inlet for stream "B" directs fluid flow into counter-flow channels 18 via respective manifold 20.

(018) Once introduced into the heat exchanger, streams "A" and "B" flow in opposing directions to each other. The hotter stream losses heat to the colder stream, thereby effecting an exchange of heat energy. The amount of heat gained in the colder stream and the amount of heat lost from the hotter stream are easily computed by conventional heat exchange analysis methods.

(019) Thus, the longitudinal bend, or jog, of the heat exchanger tubes 11, according to the present invention ensures that the entire surface of one fluid carrying tube 13 is directly adjacent on all sides to the tube surface of the other fluid, thereby creating an increase in the direct contact surface area at the interior of the tube stack where each fluid carrying tube 13 is surrounded on all sides by tubes 13 carrying the complementary counterflow fluid. However, there are compensating effects at the external surface of the heat exchange core where some of the tubes 13 do not have a corresponding adjacent contact surface. Nevertheless, in most common heat transfers situations, where there are many parallel tubes 13, the majority of the tubes will be in interior tubes and 13 while demonstrate a net improvement in heat exchanger effectiveness.

(020) In addition to being useful in aerospace power conversion systems, the heat exchanger of the present invention is useful in such apparatus and systems as engine combusters, heat sinks, and recuperators, including microchannel recuperators.

(021) Accordingly, the description for the present invention is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the best mode of carrying out the invention. The details may be varied substantially without departing from the spirit of the invention, and the exclusive use of all modifications with are within the scope of the appended claims is reserved.